Semi-Annual Report
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A. Task Objective: Algorithm Development for Global Mapping of Phycoerythrin Pigment, Dissolved Organic Matter, and Chlorophyllous Pigment

1. MODIS North Atlantic Test Site Establishment and Characterization

As previously reported, the MODIS North Atlantic Test Site has been established as originally proposed. The Test Site includes the New York Bight/Mid-Atlantic Bight/Gulf Stream/Sargasso Sea and is conveniently located north and east of GSFC/WFF. Characterization has been initiated by ship sampling, aircraft overflights, and analysis of historical data available from within the NASA AOL project since 1980. Much of the data obtained in the northwestern portion of the test site will be used for algorithm development in Case 2 waters.

a. During this 6-month reporting period the Test Site was again both characterized and used as a source of new experimental airborne active-passive ocean color data in pursuit of this team member's algorithm for the detection and mapping of the phytoplankton chlorophyll accessory pigment, phycoerythrin. Ship flow-thru phycoerythrin fluorescence spectrometer was tried (unsucccessfully) by Dr. Niel Blough (WHOI) during the field experiments in August and November 1993. This equipment will be reconfigured and new trials conducted during the field experiments in the Test Site in March-April 1994. The active (laser) airborne detection of phycoerythrin has been established since 1979 and the evidence for passive (solar) detection at 600nm was published in 1986 and 1990.

Dr. Blough also acquired filtered samples to allow further evaluation of the dissolved organic matter (DOM) within the MODIS Test Site from the Delaware Bay mouth across the shelf, slope, Gulf Stream and Sargasso Sea waters. The spectral absorption and fluorescence of these samples are being measured by Dr. Tony Vodacek, a National Research Council Resident Research Associate (RRA). These data are being used for developing algorithmic corrections for dissolved organic matter absorption.

As reported earlier, flights were conducted to the northeast of GSFC/WFF in early April 1993 to characterize the MODIS Test Site during the collapse of the spring phytoplankton bloom. In addition, this flight allowed the concurrent evaluation of a new multichannel array detector manufactured by Analytical Spectral Devices, Inc. (loaned to AOL the project). It was found that the

color sensor lacked the requisite sensitivity for ocean color spectra in a high-rate/low-integration-time mode needed to allow editing of data containing sun glint. Accordingly, a modest effort was mounted to build a suitable sensor capable of rapid spectral measurement of the relatively dark ocean. This sensor was successfully flown during the JGOFS Iron Enrichment Experiments off the coast of Ecuador in November 1993.

Additionally, the evaluation of a sea surface temperature sensor manufactured and loaned to the project by Heimann/EG&G was conducted in April 1993. The temperature sensor data evaluation indicated that the sensor had the requisite stability and accuracy needed to support the airborne active-passive ocean color measurements.Two units have been purchased for airborne use.

2. Selection of Case 1 Data Sets.

Historic airborne active-passive ocean color data acquired within Case 1 oceanic regions with the NASA Airborne Oceanographic Lidar are continually being screened for use in algorithm development. Several promising candidate data sets have been identified. In particular, AOL active-passive data in the northwestern Atlantic Ocean east of St. Johns , Newfoundland (obtained in 1989 as part of the Joint Global Ocean Flux Study of the North Atlantic Bloom Experiment) has displayed remarkable quality and freedom from non-chlorophyllous backscatterers. Similar data having non-absorbing backscatter (NAB) from coccoliths has been identified for analysis. These latter data are from the JGOFS North Atlantic Bloom Experiment conducted in 1989.

B. Other Work Accomplished

1. In-situ and Airborne Optical Characterization of MODIS North Atlantic Test Site.

A manuscript describing some of the algorithm work was published during this reporting period. The reader should consult this paper for details of the progress of the DOM retrieval using fluorescence methods. The manuscript is: Hoge, Frank E. , Anthony Vodacek, Neil V. Blough, Inherent Optical Properties of the Ocean: Retrieval of the Absorption Coefficient of Chromophoric Dissolved Organic Matter from Fluorescence Measurements, Limnology and Oceanography, 38(7) 1394-1402, 1993.

The validity of the Test Site samples and data have also been addressed during this reporting period. Specifically, the DOM absorption from prior cooperative ship experiments (see above paper) have been used to establish the levels of DOM fluorescence measured with the NASA Airborne Oceanographic Lidar in both the Atlantic and Pacific Oceans. These results were also

published during this reporting period. The reference is : Hoge, Frank E. , Robert N. Swift, James Y. Yungel, Anthony Vodacek, Fluorescence of Dissolved Organic Matter: A Comparison of North Pacific and North Atlantic Oceans during April 1991, Jour. Geophysical Res. 98, No. C12, 22,779-22,787 (1993).

Some of the data used in the above publications came from the in situ characterization of the test site as initiated on February 28, 1991 with the acquisition of surface layer samples obtained during the Surface Wave Dynamics Experiment (SWADE). As previously reported, through cooperation with Dr. Charles Flagg, arrangements were made to collect 20 samples along an in-bound track line from the Gulf Stream to the mouth of the Delaware Bay. The samples were filtered (0.45 um) to remove particulate matter other than the dissolved organic matter (DOM). Spectral absorbance of the filtered samples were acquired at Wallops, Cornell Laboratory for Environmental Remote Sensing (CLEARS), and Woods Hole Oceanographic Institute (WHOI). Spectral fluorescence of the filtered samples was also measured at CLEARS (Dr. Tony Vodacek, now a NRC Resident Research Associate at Wallops) and WHOI (Dr. Niel Blough).

As reported in the above Limnology and Oceanography paper, recovery of the absorption coefficients for the light-absorbing or chromophoric components of the dissolved organic matter (aCDOM) from their fluorescence emission has been established by laboratory analyses of the surface samples gathered from the Feb. 28, 1991 cruise as well as other cruises. These absorbance and fluorescence analyses, (and work reported by others), show that absorption coefficients in the near ultraviolet can be directly retrieved from measurements of the fluorescence emission of CDOM. Thus, absorption coefficients in the visible spectrum can potentially be obtained from the fact that CDOM absorption is exponentially related to wavelength. The errors in the laboratory fluorescence measurements were minimized through the combined use of the water Raman scatter as an internal radiometric standard and a quinine sulfate solution as a reference. This methodology reduces aCDOM algorithm retrieval errors primarily attributable to the use of commercial spectrophotometers having maximum optical path lengths of 10 cm. The use of merging technologies, such as the long-path reflecting tube absorption meter and the integrating cavity absorption meter, are suggested for future improvements to aCDOM retrieval algorithms. While the aCDOM retrieval appears feasible, the relationship to CDOM emission is susceptible to changes in DOM fluorescence yield, so the continued temporal study of marine samples from many diverse oceanic locations is needed. When applied to shipboard and aircraft laser fluorometers, this retrieval methodology and the resulting DOM absorption coefficients will be used in ocean color models and associated satellite sensor/algorithm development directly aimed at phycoerythrin retrieval. The DOM is important since it is a major interferant to the detection and quantification of chlorophyll and chlorophyll accessory pigments (CAP) such as phycoerythrin.

Morevoer, DOM is a contributor to the carbon cycle itself.

2. In Situ Optical Characterization of the MODIS North Atlantic Test Site.

The continued characterization of the Test Site is partially described in the previously mentioned publication in Limnology and Oceanography.

For the MODIS Test Site during August, 1993 and November, 1993 cooperative overflights of EOS Interdisciplinary Team member, Dr. N. Blough, were conducted. Dr. Blough and NRC/RRA, Dr. Anthony Vodacek, used the Research Vessel Cape Henlopen to conduct DOM investigations in the Mid-Atlantic Bight (and within our own Test Site). The shipboard phycoerythrin fluorescence experiments were unsuccessful but will be tried again on a subsequent mission. Dr. Dan Repeta (WHOI) is also analysing samples to determine the phycoerythrin pigment concentration, but the results are not yet available. Otherwise, excellent ship and aircraft overflight data were obtained. This data is now undergoing analysis.

1. Phycoerythrin Algorithm Development Activities

Plans call for us to again directly address the quantification of the phycoerythrin signal as outlined in the original MODIS proposal. To assist us in this endeavor, we will utilize the data obtained by Dr. Maria Vernet (during a cruise conducted during the last Semi-annual reporting period). Additional (1) CDOM data and (2) first-time ship calibration of the airborne phycoerythrin-to-water Raman signal is potentially obtainable from this field work.

2. Chlorophyll Pigment and CDOM Corrections to the Phycoerythrin Algorithm.

Major perturbations or influence to the ocean color spectrum are provided by chlorophyll and CDOM. These oceanic constituents significantly impede the retrieval of phycoerythrin pigment from the upwelled radiances. Accordingly, they must be dealt with in a systematic way in order to understand their effects and the impact on the retrieval of phycoerythrin and its ultimate quantification. In situ and airborne data gathered to date will be used to model the effects and to ascertain the extent that they can be quantified and removed.

3. Other Data Acquisition for Algorithm Development

During late October and early November 1993 flights were conducted in cooperation with NSF's Joint Global Ocean Flux Study of Iron Enrichment in the Eastern Equatorial Pacific. Considerable Case 1 ocean color data was obtained during these JGOFS flights both during the mapping of the ship-deployed iron and during the transit to and from the experiment site at -90W and -5S. Quality algorithm-development ocean color data was also

obtained on pre-determined transects within the naturally-occuring Galapagos Island plume. The transit flights from Wallops Flight Facility to Guayaquil (via Belize) likewise yielded ocean color data suitable for algorithm development. During the latter transit flights, numerous watermasses were crossed. These data are being evaluated.

C. Anticipated Activities During Next Half Year.

1. Additional flights of the NASA Airborne Oceanographic Lidar are planned within the MODIS Test Site. Specifically, Dr. Neil Blough will be overflown in the Middle Atlantic Bight in March/April 1994. Dr. Tom Fisher/Dr. Larry Harding (Horn Point Environmental Laboratory/Univ. Md.) together with Dr. Frank Muller-Karger will be overflown in the region extending from the Chesapeake Bay mouth to Cape Hatteras.

2. Plans are being made to participate in the JGOFS Arabian Sea Experiment in July 1995. This is an opportunity to obtain data in an entirely different oceanic province. As did the Iron Enrichment Expeeriment flights, these flights will serve as a valuable data source for algorithm development. This should contribute to the goal for universality of the algorithms being developed.

D. Other Concerns

The lack of a 600nm band on MODIS-N is the biggest problem facing the retrieval of the phycoerythrin pigment on the first sensor launch. Plans to synthesize a 600nm band from existing bands will be performance tested using data obtained over actual oceanic phycoerythrin pigment using the 32-band AOL passive ocean color subsystem (POCS). Recent studies of available models, however, suggests that the retrieval of the phycoerythrin pigment at the absorption peaks of 495nm (phycourobilin, PUB) and 545nm (phycoerythrobilin, PEB) may possibly be achieved using the 490nm and 555nm MODIS bands. Such retrievals will require a highly accurate model to account for the significant amounts of chlorophyll and DOM absorption occuring simultaneously with the phycoerythrin absorptions .